## REMARKS

Claims 25-38 stand rejected in the Office Action. Claims 20-24 have been withdrawn from consideration in response to the Restriction Requirement and are canceled with this amendment. Claims 25, 28, and 32 have been amended in this Response, while new claim 39 is offered. Upon entry of the amendments, claims 25-39 remain pending in the Application.

Claim 28 has been amended to correct claim dependency. Support for the Amendment to claim 25 is found in the specification as originally filed, for example on page 3, lines 14-17 and on page 7, lines 10-17. Support for the amendment to claim 32 is also found in the passages supporting the Amendment to claim 25. Support for new claim 39 is found in the specification, for example on page 6, lines 10-12. Applicants respectfully request entry of the amendments.

### CLAIM OBJECTIONS

Applicants have corrected the dependency of claim 28, as suggested by the Examiner. It is believed that the amendments to claim 28 suffice to remove the claim objection.

### REJECTION UNDER 35 U.S.C. § 102

Claims 25, 29, 30, 31 and 32 stand rejected under 35 U.S.C. § 102(b) as being anticipated by Dash (U.S. Pat. No. 2,491,479).

The Examiner states that the Dash reference shows arc welding an aluminum stud to an aluminum plate. The Examiner further asserts that, since the aluminum alloy is taught as containing 0.2% titanium, the titanium would inherently comprise the surface of the stud. Applicants respectfully traverse the rejection as applied to the amended claims and request reconsideration.

Applicants have amended claim 25 and 32 to more clearly define the invention. In particular, Applicants have added language supported by the specification that the titanium on the surface on the head of the aluminum weld stud is provided in the form of a layer of titanium containing material. Such a limitation is not present in the Dash reference—as noted above, the Dash reference teaches the titanium is merely part of the aluminum alloy, and is not present as a layer on the surface. Rejected claims 29-31 depend from claim 25 and so include the limitation that the titanium containing material is present as a layer on the surface of the stud. Because the amended claims contain at least one element or limitation not found in the Dash reference, they are patentable over the Dash reference under § 102. Accordingly, Applicants respectfully request that the rejection of claims 25, 29, 30, 31, and 32 over the Dash reference be withdrawn.

## REJECTION UNDER 35 U.S.C. § 103

Claims 26-28, and 33-38 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over the Dash reference as applied to claims 25 and 32, and further in view of Martin (U.S. Patent 2,670,424) and Konnert (U.S. Patent 4,326,894). The Martin reference appears to be cited for a teaching of a weld stud coated with titanium, and the Konnert reference appears to teach applying a titanium material to a surface by using an acidic solution comprising titanium ions. The Office Action states that the teachings of the Martin reference and the Konnert reference make-up for the deficiency of the Dash reference, which does not disclose applying a coating to a stud surface with an acidic solution. Applicants respectfully traverse the rejections and respectfully request reconsideration.

For a rejection of claims over a combination of references under § 103, the references when combined must teach or disclose every element of the claims. Further, there must be a

motivation to combine the teachings of the references in order to arrive at the subject matter of the claims. Just because references can be combined to arrive at the claimed subject matter, such combination is not obvious unless there is a suggestion that it would be desirable to do so. In assessing the teaching of cited references, it is appropriate to consider the entire teaching of the references and the interpretation a person of skill in the art would apply to those teachings. In particular, portions of the reference that teach away from making the combination should be considered in determining whether the invention as a whole would have been obvious to a person of skill in the art.

As noted above, the Dash reference does not disclose a layer of titanium on an aluminum weld stud, as recited by the amended claims 25 and 32. Accordingly, these and other features of claims 26-28 and 33-38 must be supplied by the cited references Martin and Konnert. Dash discloses an aluminum stud, but it does not teach a coating of titanium on the stud.

The Martin reference teaches away from coating an aluminum stud with titanium. Martin is drawn to the welding of steel or steel alloy studs to plates made of steel. Column 1, line 12-14. Aluminum is preferred for metallizing a steel stud, but other alloys having the required characteristics may be used depending on the material the stud is made of. Column 3, lines 9-13. The required characteristics include that the metal for metallizing the (steel) surface of the stud have a higher conductivity than the stud material. Column 2, lines 42-45.

In the current claims, on the other hand, the metal (titanium) forming a coating on the studs has a lower conductivity than the stud metal (aluminum). Thus, while Martin teaches aluminum is preferred to put on an iron or steel stud, it specifically teaches away from using a poorly conductive metal, such as titanium, to coat a highly conductive material such as aluminum.

The relative conductivities just mentioned are well-known and can be looked up in standard treatises. For example, it is known that aluminum is more conductive than iron or steel, and that titanium is less conductive than aluminum. Attention is respectfully drawn to the attached web page from the Newsletter of the American Metal Market, available at www.amm.com. The relative conductivity of aluminum (based on copper as 100) is given as from 39-59 while the relative conductivity of titanium is given as 5 and that of steel is given as 3-15. Thus, the conductivity of the titanium is nearly an order of magnitude lower than that of aluminum. The conductivity measurements in the table are consistent with values of resistivity available in standard treatises such as the attached pages from the Metal Handbook, 8th Edition, published by The American Society for Metals. The electrical resistivity of titanium is given as 42 microhm-cm, while the resistivity of aluminum is given as 2.6548 microhm-cm. Because the electrical resistivity is the reciprocal of the electrical conductivity, the Metals Handbook data show the electrical conductivity of titanium is more than an order of magnitude less than the conductivity of aluminum.

Other passages in the Martin reference do not reverse the express teaching away from titanium on aluminum. The Martin reference teaches that is preferred to metallize a steel stud with aluminum, but does indicate that other metals may be placed on studs made of other materials. However, the reference is very clear to state that other metals or alloys chosen for the metallization must have the required characteristics (column 3, lines 11, discussed above). Since the required characteristics include a metal having a higher conductivity than the material of the stud, this amounts to an express teaching that metals of low conductivity (such as titanium) are to be avoided when using a highly conductive material such as aluminum for the stud.

Further, the Martin reference states that there is "no limitation...as to the specific metallizing materials". Column 4, lines 38-40. But these lines directly contradict the earlier teaching that metals must have required characteristics, including higher conductivity than the stud material. Because even the claims of the reference recite the "higher electrical conductivity" feature of the metallizing material, the person of skill in the art would discount the statement that there is no limitation. The reference at Column 4 goes on to suggest for the use with steel or steel alloy studs, other metals such as titanium, manganese, and vanadium can be used. But this is no teaching to coat an aluminum stud with titanium. In light of the reference's express teaching against combining titanium with an aluminum stud, Applicants respectfully submit that the reference at Column 4 does not motivate one of skill in the art to modify the disclosure of the Dash to arrive at the subject matter.

The Konnert reference does not overcome the deficiencies of the Dash and Martin references as just discussed. The Konnert reference is directed to preparing conversion coatings. The reference simply does not motivate one of skill in the art to apply a titanium coating to an aluminum stud in light of the teachings of the Martin reference discussed above. For this reason, Applicants respectfully submit that there is no motivation to combine the references.

For the reasons discussed above, Applicants respectfully submit the amended claims are patentable over the cited references. Accordingly, Applicants respectfully request the rejection be withdrawn.

Claim 39 adds a further limitation that distinguishes the claimed invention from the cited references. None of the references alone or in combination teach or suggest providing a (titanium) layer of sufficient thickness to prevent formation of aluminum oxide on the stud. For this and the reasons discussed above, Applicants believe claim 39 is patentable over the cited

references.

<u>CONCLUSION</u>

It is believed that all of the stated grounds of rejection have been properly traversed, accommodated, or rendered moot. Applicant therefore respectfully requests that the Examiner reconsider and withdraw all presently outstanding rejections. It is believed that a full and complete response has been made to the outstanding Office Action, and as such, the present application is in condition for allowance. Thus, prompt and favorable consideration of this amendment is respectfully requested. If the Examiner believes that personal communication will expedite prosecution of this application, the Examiner is invited to telephone the undersigned at (248) 641-1600.

Respectfully submitted,

Dated: January 28, 2004

By: Robert M Siminski

Robert M. Siminski,
Reg. No. 36,007

HARNESS, DICKEY & PIERCE, P.L.C.
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Bloomfield Hills, Michigan 48303
(248) 641-1600

RMS/MAF/cg

# Electrical Conductivity of Metals

*This page is best viewed in Netscape 2.0+ or other table-capable browsers.*
The table originally appeared in *AMM*'s annual *Metal Statistics* book.

| Metal | Relative Conductivity* | Temperature Coefficient of Resistance** | Tensile Strength (lbs./sq. in.) | Composition of Earth's Crust (% by Weight) |
|---|---|---|---|---|
| *Aluminum (2S; pure)* | 59 | 0.0039 | 30,000 | 8.1 |
| *Aluminum (alloys):* | | | | |
| • *Soft-annealed* | 45-50 | — | — | — |
| • *Heat-treated* | 30-45 | — | — | — |
| *Brass* | 28 | 0.002-0.007 | 70,000 | — |
| *Cadmium* | 19 | 0.0038 | — | .0001 |
| *Chromium* | 55 | — | — | .02 |
| *Climax* | 1.83 | 0.0007 | 150,000 | — |
| *Cobalt* | 16.3 | 0.0033 | — | .002 |
| *Constantin* | 3.24 | 0.00001 | 120,000 | — |
| *Copper:* | | | | |
| *Hard drawn* | 89.5 | 0.00382 | 60,000 | — |
| • *Annealed* | 100 | 0.00393 | 30,000 | .007 |
| *Everdur* | 6 | — | — | — |
| *Gold* | 65 | 0.0034 | 20,000 | .0000005 |
| *Iron:* | | | | |
| • *Pure* | 17.7 | 0.005 | — | 5.0 |
| • *Cast* | 2-12 | — | — | — |
| • *Wrought* | 11.4 | — | — | — |
| *Lead* | 7 | 0.0039 | 3,000 | .002 |
| *Magnesium* | — | 0.004 | 33,000 | 2.1 |
| *Manganin* | 3.7 | 0.00001 | 150,000 | — |
| *Mercury* | 1.66 | 0.00089 | 0 | .00005 |
| *Molybdenum* | 33.2 | 0.004 | — | .001 |
| *Monel* | 4 | 0.002 | 160,000 | — |
| *Nichrome* | 1.45 | 0.0004 | 150,000 | — |
| *Nickel* | 12-16 | 0.006 | 120,000 | .008 |
| *Nickel silver (18%)* | 5.3 | 0.00014 | 150,000 | — |
| *Phosphor bronze* | 36 | 0.0018 | 25,000 | — |
| *Platinum* | 15 | 0.003 | 55,000 | .0000005 |
| *Silver* | 106 | 0.0038 | 42,000 | .00001 |
| *Steel* | 3-15 | 0.004-0.005 | 42,000-230,000 | — |
| *Tin* | 13 | 0.0042 | 4,000 | .004 |
| *Titanium* | 5 | — | 50,000 | .4 |
| *Titanium, 6A14V* | 5 | — | 130,000 | — |
| *Tungsten* | 28.9 | 0.0045 | 500,000 | .007 |
| *Zinc* | 28.2 | 0.0037 | 10,000 | .01 |

** At 20° Celsius, based on copper as 100.*
*** Per degree C at 20° C.*
*Note: The conductivity of various metals is subject to variation according to processing and alloy composition.*

(LEFT) A single crystal of antimony, cleared and deeply etched by an acid mixture along (111) planes *(Bell Telephone Laboratories, Inc.)*. (RIGHT) Sahara desert sand dunes in southern Libya *(Aero Service Corp.)*.



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The subject matter of
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systematically: a general
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Cross references guide t
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name.

The adjectives electric
the following senses. Electr
arising from, actuated by,

is the low cathode potential fall and the very high current density. It is generally felt that the predominant effect in the production of the large number of electrons at the cathode necessary for the arc is thermionic emission. This is consistent with the very high temperatures known to exist either generally or locally on the cathode. Although the arc type of discharge has very great commercial value, the mechanism of its operation is not very well understood.

In addition to these general types of conduction, there are very special cases of considerable interest. Some of these are the corona discharge, radio-frequency or electrodeless discharge, hot-cathode discharge, and discharges in the presence of a magnetic field. [C.H.MI.]

*Bibliography*: G. P. Harnwell, *Principles of Electricity and Electromagnetism*, 2d ed., 1949; L. B. Loeb, *Fundamental Processes of Electrical Discharge in Gases*, 1939; J. Millman and S. Seely, *Electronics*, 2d ed., 1951.

## Electrical conductivity of metals

Electric currents in metals are caused by mobile, relatively free electrons that are not bound to any particular atom and can wander throughout the metal. In general, the conductivity of metals is higher than that of other materials, and decreases with rising temperature. At temperatures near absolute zero, certain metals become superconductors, possessing infinite conductivity. For an extended discussion of this phenomenon, *see* SUPERCONDUCTIVITY. The conductivities of a number of common metals at 0°C are as follows:

| *Metal* | *Conductivity, (ohm-meter)*$^{-1}$ |
|---|---|
| Silver | 66 |
| Copper | 64.5 |
| Gold | 49 |
| Aluminum | 40 |
| Magnesium | 25.4 |
| Sodium | 23.4 |
| Tungsten | 20.4 |
| Potassium | 16 |
| Lithium | 11.8 |
| Iron | 11.5 |
| Cesium | 5.2 |

The current density (current per unit area) in a conductor is proportional to the electric field in the conductor; that is, $J = \sigma \cdot E$ where J is the current density and E is the electric field intensity. The proportionality constant $\sigma$ is called the electrical conductivity. In mks units J is in amperes per square meter, E is in volts per meter and $\sigma$ has the dimensions of (ohm-meter)$^{-1}$. In isotropic or nearly isotropic materials, such as polycrystalline metals or liquids, J is in the same direction as E, and $\sigma$ reduces to a scalar constant. In this case $\sigma$ is simply the reciprocal of the resistivity $\rho$ (*see* RESISTIVITY, ELECTRICAL). In general, however, $\sigma$ must be defined as a tensor, called the conductivity tensor.



Electrons possess negative charge; hence the direction of current flow is opposite to that of the flow of electrons. In a solid, however, electrons may, under certain conditions, move under the influence of an electric field in such a manner that the net effect is the same as though positively charged carriers of approximately electronic mass were responsible for the current flow. It is then common to speak of current due to holes, these holes being thought of as charge carriers of positive mass and charge (*see* HOLES IN SOLIDS). Frequently, especially in the case of polyvalent metals (and also in semiconductors), the experimental results are described most conveniently by assuming that holes, as well as ordinary electrons, contribute to charge flow. In the theory of conductivity one then speaks of a two-band model.

In the more general sense the theory of electrical conductivity of metals encompasses all phenomena which relate to the transport of electrons in metals. This includes the thermoelectric effects (Peltier, Thomson, and Seebeck effects), the isothermal magnetic effects (Hall, Corbino, and magnetoresistance effects), and the thermomagnetic effects (Nernst, Ettinghausen, and Righi-Leduc effects). Moreover, since transport of charge is accompanied by transport of electronic mass and energy, the general formulation of the theory also contains within its framework the theory of that portion of the thermal conductivity which is due to the presence of mobile electrons or holes in the metal. *See* CONDUCTION (HEAT); *see also* BOLTZMANN TRANSPORT EQUATION; FREE-ELECTRON THEORY OF METALS; HALL EFFECT; MAGNETORESISTANCE; RELAXATION TIME (ELECTRONS); THERMOELECTRICITY; THERMOMAGNETIC EFFECTS; WIEDEMANN-FRANZ LAW. [F.J.B.]

## Electrical degree

A unit equal to 1/360 of a complete cycle of electric current or voltage. In an electric machine it is 1/360 of the angle subtended at the axis by two consecutive field poles of like polarity, since the voltage wave generated in a conductor completes one cycle when it traverses one pair of poles. The term mechanical degree is used to designate the space angle between the two positions about the axis of the machine. The number of electrical degrees equals the number of mechanical degrees multiplied by the number of pairs of poles on the machine. [A.R.E.]

## Electrical engineering

A branch of engineering dealing primarily with electricity and magnetism and devoted to utilization of the forces of nature and materials for the benefit of mankind (*see* ENGINEERING). Electrical engineering encompasses many phases of other engineering sciences and the physical sciences; it includes research, invention, development design, application, and education. Many phases of electrical engineering are based on applications of higher mathematics.

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closely identified with im
relatively few scientists an
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of electrical engineering,
sider five eras of developme

**First era.** As early as t
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behavior of static electri
1603), personal physician
experimented with electric
In 1750 Benjamin Frankli
was electrical in nature. I
covered anything that w
standpoint of the applica
covery of the presence o
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ity. Such knowledge was
Applications of electrical
pletely absent in this era.
NETISM.

**Second era.** The secon
in electrochemical develo
deposition was discovered
A. Carlisle in 1800 and in
discovered the principle
The voltaic cell was one
discoveries in the history
cause it provided a contin
ble amounts of electric p
voltage. *See* BATTERY (EL
was used as an essential
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telegraph.

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cal in 1837, and patented
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Few developments have
American life than Mor
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The growth of electrical
in extensive engineering,
equipment, and the birth
adding much to the wealth
at the same time making p
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# METALS HANDBOOK

8th Edition

VOL. 1

## Properties and Selection of Metals

prepared under the direction of the
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## Aluminum (99.996%)


Compiled by A. W. DEMMLER, JR.*


C 1 *Density.* At 68 F (20 C), 2.6989 g per cu cm (0.09751 lb per cu in.); at 77 F (25 C), 2.6978 g per cu cm (0.09747 lb per cu in.)

D 2 *Melting point.* 1220.4 F (660.2 C)

4 *Boiling point.* 4442 F (2450 C)

6 *Thermal expansion.*

| Temperature range, C | Average coefficient, micro-in./in./°C |
|---|---|
| -200 to 20 | 18.0 |
| -150 to 20 | 19.9 |
| -100 to 20 | 21.0 |
| -50 to 20 | 21.8 |
| 20 to 100 | 23.6 |
| 20 to 200 | 24.5 |
| 20 to 300 | 25.5 |
| 20 to 400 | 26.4 |
| 20 to 500 | 27.4 |

11 *Specific heat* at 212 F (100 C). 0.224 cal per g

13 *Latent heat of fusion.* 94.5 cal per g

18 *Heat of combustion.* 7420 cal per g to $\alpha Al_2O_3$ at 77 F (25 C)

E 1 *Electrical conductivity.* 64.94% IACS

2 *Electrical resistivity* at 68 F (20 C). 2.6548 microhm-cm

5 *Temperature coefficient of electrical resistivity,* 68 F (20 C). 0.00429 per °C

F 1 *Reflectivity.* 90% for white light from a tungsten filament; 86 to 87% in range between λ = 2200 and 2500 A; 96% for λ = 10,000 A (1 micron); 97% for λ = 11,000 to 100,000 A (1.1 to 10 microns)

5 *Emissivity* at 77 F (25 C). 0.030 in air

G 2 *Magnetic susceptibility.* 0.6 × $10^{-6}$ cgs

J 1 *Crystal structure.* Face-centered cubic; $a$ = 4.0491 A

K 1 *Mechanical properties.* Modulus of elasticity, 9,000,000 psi

| Property | Annealed | Cold rolled 75% |
|---|---|---|
| Tensile strength, psi | 6,800 | 16,300 |
| Yield strength, psi | 1,700 | 15,400 |
| Elongation, %(a) | 60 | 5 |
| Brinell hardness(b) | 17 | 27 |

(a) Sheet specimens.
(b) 500-kg load, 10-mm ball.

*Aluminum Co. of America

## Antimony


Compiled by K. C. LI†


B 1 *Typical uses.* Alloyed with lead for batteries. Alloyed with tin or lead for bearings and type metal. In the form of an oxide ($Sb_2O_3$), in enamels, pigments and fireproofing materials.

C 1 *Density* at 68 F (20 C). 6.62 g per cu cm (0.239 lb per cu in.)

D 1 *Melting point.* 1166.9 F (630.5 C)

4 *Boiling point.* 2516 F (1380 C)

6 *Thermal expansion* 68 to 140 F (20 to 60 C). 0.0000085 to 0.0000108 per °C, the value depending on the crystal orientation in the polycrystalline material.

11 *Specific heat* at 68 F (20 C). 0.049 cal per g

13 *Latent heat of fusion.* 38.3 cal per g

15 *Latent heat of vaporization.* 373 cal per g

16 *Thermal conductivity.* 0.045 cal/sq cm/cm/sec/°C

E 2 *Electrical resistivity* at 32 F (0 C). 39.0 microhm-cm

F 1 *Reflectivity.* 70% at λ = 5890 A

G 2 *Mass magnetic susceptibility.* -0.87 cgs

I 2 *Resistance to specific agents.*

| Corrosive agent | Resistance |
|---|---|
| Air | Moderate general attack when air is moist and light is present |
| Alkalis and alkali salts | General attack |
| Ammonia | Resistant |
| Aqua regia | Severe general attack |
| Carbon dioxide | Resistant |
| Chlorine | Severe general attack |
| Hydrochloric acid | Moderate attack in presence of air |
| Hydrofluoric acid | Resistant |
| Nitric acid | Severe general attack |
| Sulfuric acid | Severe general attack by warm concentrated acid; resistant to cold or dilute acid |

†President, Wah Chang Corp.


This section was compiled with the help of the ASM Committee on Pure Metals, with membership as follows: WM. A. PENNINGTON, *Chairman*, Professor of Metallurgy, University of Maryland; C. S. BARRETT, Professor, Institute for the Study of Metals, University of Chicago; J. H. BECHTOLD, Manager, Metallurgy Dept., Research Laboratories, Westinghouse Electric Corp.; EDWARD EPREMIAN, Technical Advisor, Union Carbide Metals Co., Union Carbide Corp.

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dissociation pressure. It is also used as a deoxidant and in electronic tubes and lamps for controlling starting voltages and maintaining stability.

2 *Precautions in use.* Thorium is a reactive metal and, depending on its chemical and physical form, is potentially toxic chemically and radiologically.

C 1 *Density* at 77 F (25 C). X-ray: 11.72 g per cu cm; bomb-reduced (as cast): 11.5 to 11.6 g per cu cm; arc-melted iodide: 11.66 g per cu cm

D 1 *Melting point.* 3182 F (1750 C)

4 *Boiling point.* 6332 to 7592 F (3500 to 4200 C)

6 *Thermal expansion* (linear), 77 to 1832 F (25 to 1000 C). 12.5 micro-in. per in. per °C (iodide thorium)

13 *Latent heat of fusion.* <4600 cal per mol

15 *Latent heat of vaporization.* 130,000 to 145,000 cal per mol

16 *Thermal conductivity* at 212 F (100 C). 0.090 cal/cm/sec/°C

E 2 *Electrical resistivity* at 273 K. 13 microhm-cm

5 *Temperature coefficient of electrical resistivity,* 32 to 212 F (0 to 100 C). 0.0038 per °C

15 *Hall coefficient.* $-8.8 \times 10^{-5}$ cu cm per coulomb

F 4 *Color.* Silvery white

G 2 *Mass magnetic susceptibility* at 90 K. $0.66 \times 10^{6}$ emu per g

I 1 *General resistance to corrosion.* Reacts readily in air and rather slowly in water (at 212 F). Below 1650 F, thorium is resistant to most liquid metals, with the exception of aluminum. Up to 1472 F, it is notably resistant to sodium-potassium.

J 1 *Crystal structure.* Face-centered cubic up to 2552 F (1400 C), $a = 5.08$ kX; body-centered cubic above 2552 F.

K 1 *Mechanical properties.* Average properties of as-cast, bomb-reduced thorium: tensile strength, 31,700 psi; yield strength, 20,900 psi; elongation, 34%; reduction in area, 35%; Vickers hardness (arc-melted iodide), 32 to 42; modulus of elasticity, 7 to 10 million psi. See table.

**Tensile Properties of As-Cast Bomb-Reduced Thorium(a)**

| Value | Tensile strength, psi | Yield strength, psi | Elongation in 1 in., % | Reduction in area, % |
|---|---|---|---|---|
| Max .... | 48,800 | 30,100 | 58 | 56 |
| Min .... | 23,900 | 13,800 | 8 | 7 |
| Avg .... | 31,700 | 20,900 | 34 | 35 |

(a) 0.02 to 0.08% C. Yield strength, 110 samples tested; other properties, 107 samples tested.

SOURCE: G. Murphy, R. T. Othmer and R. E. Uhrig, Ames Laboratory, Iowa State University

N *Casting.* Current melting practice includes: (a) induction melting in a crucible under a protective atmosphere of argon or in a vacuum, and (b) consumable-electrode arc melting in a reduced-pressure argon-helium atmosphere.

7 *Hot working temperature.* 1300 to 1750 F (705 to 955 C)

11 *Suited to forming* by machining, turning, grinding, threading, drilling, rolling, swaging, forging, drawing and extruding

14 *Sintering temperature.* 1830 F (1000 C) in vacuum

15 *Heat treatment.* Calcium-reduced metal is annealed by holding at 1200 to 1380 F for 1 hr and slow cooling. Iodide thorium is similarly annealed at 1110 to 1290 F.

## Thulium

*See page 1230*

## Tin

*See page 1142*

## Titanium (99.9%)

Compiled by W. STUART LYMAN*

A 1 *Common name.* Iodide titanium, electrolytic titanium

B 1 *Typical uses.* Experimentation and research; commercial applications requiring freedom from interstitial alloying elements (oxygen, nitrogen, carbon and hydrogen).

C 1 *Density* at 68 F (20 C). 0.163 lb per cu in. (4.507 ± 0.005 g per cu cm); beta titanium at 1625 F, 0.156 lb per cu in. (4.35 g per cu cm) (from indirect measurements)

D 1 *Liquidus temperature.* 3035 ± 18 F (1668 ± 10 C)

4 *Boiling point* at 1 atmosphere. 5900 F (3260 C) (estimated)

5 *Vapor pressure* from 1587 to 1698 K.

$$\log P = 7.7960 - \frac{24{,}644}{T} - 0.000227T$$

6 *Thermal expansion* at 68 F (20 C). $4.67 \times 10^{-6}$ in./in./°F; at 1830 F, $5.6 \times 10^{-6}$ in./in./°F (estimated)

7 *Thermal expansion in crystallographic direction* (calculated from lattice parameters).

| Temperature, F | Direction | Expansion, micro-in./in./°F |
|---|---|---|
| 68 to 750 | ...Perpendicular to $c$ axis | 5.66 |
| 68 to 1290 | ...Perpendicular to $c$ axis | 6.13 |
| 68 to 1290 | ...Along $c$ axis | 7.14 |

11 *Specific heat* below 13 K (−435 F). Cp (cal/mole/°K) $= 8.08 \times 10^{-4} + 0.621 \times 10^{-5}T^{3}$

Above room temperature, Cp (cal/mole/°K) $= 7.654 - 4.2546 \times 10^{-4}T - 1.236 \times 10^{5}T^{-2}$

| Temp, K | $C_p$, cal/mole/°K | Temp, K | $C_p$, cal/mole/°K |
|---|---|---|---|
| 50 | 1.136 | 500 | 6.947 |
| 75 | 2.402 | 550 | 7.011 |
| 100 | 3.434 | 600 | 7.055 |
| 125 | 4.155 | 650 | 7.085 |
| 150 | 4.684 | 700 | 7.104 |
| 175 | 5.043 | 750 | 7.115 |
| 200 | 5.321 | 800 | 7.121 |
| 225 | 5.539 | 850 | 7.121 |
| 250 | 5.713 | 900 | 7.119 |
| 275 | 5.864 | 950 | 7.113 |
| 298.15 | 5.976 | 1000 | 7.105 |
| 300 | 6.153 | 1050 | 7.095 |
| 350 | 6.496 | 1100 | 7.084 |
| 400 | 6.711 | 1150 | 7.071 |
| 450 | 6.852 | | |

13 *Latent heat of fusion.* 5000 cal per mole (estimated)

14 *Latent heat of transformation.* 1050 cal per mole (estimated)

15 *Latent heat of vaporization.* 112,500 cal per mole (estimated)

16 *Thermal conductivity* at −400 F. 6.6 Btu/sq ft/ft/hr/°F

E 2 *Electrical resistivity* at 68 F. 42.0 microhm-cm; from 68 to 1800 F, see graph.

15 *Hall coefficient.* +1.82 (± 0.2) $\times 10^{-13}$ volt-cm-amp$^{-1}$-oersted$^{-1}$

16 *Supraconductivity.* Critical temperature: 0.37 to 0.56 K

F 5 *Total emissivity.* 0.30 at 1316 F

G 2 *Magnetic susceptibility* at room temperature. 3.17 (± 0.03) $\times 10^{-6}$ emu per g

H 1 *Velocity of sound.* 16,300 ft per sec

I 1 *General resistance to corrosion.* Better than that of 99.2 and 99.0% Ti alloys (see page 1153)

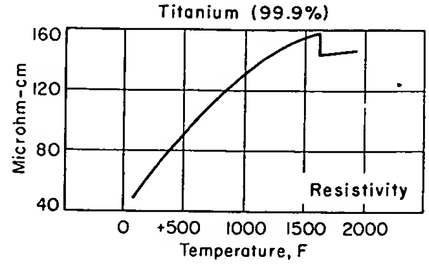
J 1 *Crystal structure.* Alpha, hexagonal, close-packed, below 1620 F (882.5 C); beta, body-centered cubic from 1620 F to melting point;

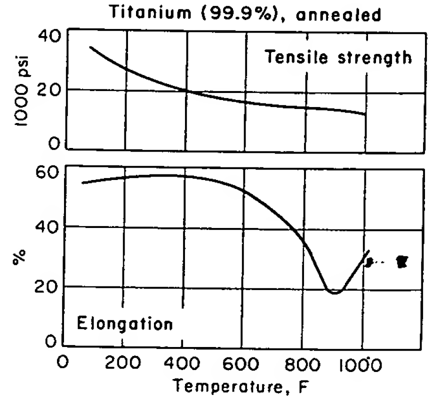
alpha: $a = 2.95030$ A, $c = 4.68312$ A, $c/a = 1.5873$

beta: $a = 3.32$ A at 1650 F

K 1 *Mechanical properties* (typical) at room temperature. Tensile strength, 34,000 psi; 0.2% yield strength, 20,000 psi; elongation in 2 in., 54%; minimum bend radius, less than 1t. See graph for properties at elevated temperatures, top of next column.

*Battelle Memorial Institute




## Tungsten

Compiled by DALLAS T. HURD†

B 1 *Typical uses.* As an alloying element in ferrous alloys and tool steels; in hard metal carbide tools; as filament or sheet in lamps and electron tubes; in missile and space vehicle components (see page 489)

C 1 *Density* at 68 F (20 C). 19.3 g per cu cm (0.697 lb per cu in.)

3 *Compressibility* at 68 F (20 C). $2.8 \times 10^{-7}$ per megabar. This value is the smallest for any metal.

D 1 *Melting point.* 6170 F (3410 C)

4 *Boiling point.* 10,706 F (5930 C)

6 *Thermal expansion.* 4.6 micro-in. per in. per °C at 27 C; 5.2 at 1027 C; 7.3 at 2100 C.

11 *Specific heat.* 0.033 cal/g/°C

12 *Heat capacity.* $C_p$ (cal/deg/mol) $= 5.74 + 0.76 \times 10^{-3}t$ ($t =$ °K over the range from 298 to 2000 K)

13 *Heat of fusion.* 44 cal per g

15 *Heat of vaporization.* 1150 cal per g

16 *Thermal conductivity,* cal/cm/sec/°C.

| °C | 0 | 500 | 1000 | 2000 |
|---|---|---|---|---|
| Value | 0.397 | 0.29 | 0.27 | 0.25 |

19 *Recrystallization temperature.* 1832 to 2192 F (1000 to 1200 C) for 1 hr, depending on purity and degree of cold work for commercial tungsten, but may range up to more than 3600 F (2000 C) for alloyed or thoriated tungsten.

20 *Vapor pressure* ($P$ = atmosphere, $t$ = °K). Solid to melting point, $\log_{10} P = \frac{-47{,}300}{t} - 1.931 \log t + 15.45$; liquid,

$$\log P = \frac{-45{,}600}{t} - 2.01 \log t + 15.25$$

22 *Entropy* at 77 F (25 C). 8 cal/mol/°C

E 2 *Electrical resistivity* (drawn wire).

| Temp, C | Microhm-cm | Temp, C | Microhm-cm |
|---|---|---|---|
| 27 | 5.65 | 1827 | 59.05 |
| 327 | 13.07 | 2727 | 90.40 |
| 627 | 21.35 | 3227 | 108.5 |
| 927 | 30.26 | | |

3 *Work function.* 4.56 ev

4 *Electron emission,* milliamperes per sq cm. At 1000 C, $3.2 \times 10^{-10}$; at 2000 C, $3 \times 10^{-2}$; at 3000 C, 84.

†General Electric Co.